EFFECTS OF SULPHUR DIOXIDE AND HEAVY METALS ON THE WAWA AREA SOILS AND VEGETATION (1974)

by
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Ministry of the Environment

Northeastern Region
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1. Sulphur Dioxide Levels in the Wawa Area During the 1974 Season:

a) Introduction:

Ground level concentrations of sulphur dioxide emitted from the Algoma Ore Division, Algoma Steel Corporation sinter plant at Wawa, Ontario were monitored by the Ontario Ministry of the Environment during the 1974 growing season (May - October). Two continuous sulphur dioxide monitors and a network of 9 sulphation candles made up the survey. One continuous recorder was operated at 29 Hillcrest Avenue, Wawa and the other at Goudreau, 35 kilometres northeast of Wawa. Sulphation candles were exposed at the 9 vegetation study plots in the area northeast of Wawa. The locations of the sinter plant, SO_2 monitors and vegetation study plots are shown in figure 1.

b) Sinter Production and SO_2 Emissions at the Wawa Sinter Plant During 1974 (June Through September):

Data supplied by the Algoma Ore Division, Algoma Steel Corporation Ltd. indicate that 1,058,773 gross tons of ore were processed during the months of June, July, August and September of 1974 (see table 1). From this tonnage 664,744 tons of sinter were produced and 63,194 tons of SO_2 were emitted to the atmosphere. Sinter production during 1974 was about 2% less than for the same period in 1973 and the emissions of SO_2 were down about 4%.

c) Sulphur Dioxide Levels in the Town of Wawa:

Ground level concentrations of sulphur dioxide were monitored at 29 Hillcrest Avenue, Wawa from May 15th., 1974 to October 17th., 1974. The 1974 season was the sixth season a continuous analyser has been operated in Wawa. A summary of the SO_2 data collected at this station during the last five years is shown in table 2.

Valid data were collected for over 95% of the period May 15th. to October 17th., 1974 at the Wawa station. Some level of SO_2 was recorded during 15% of the time during the season. During June and July SO_2 was recorded approximately 20% of the time and about 10% of the time during August, September and October. The frequency of SO_2 during 1974 was considerably less than in 1973, but higher than in 1970, 1971 and 1972.

The average concentration of SO_2, for SO_2 periods only, was higher in 1974 than 1973, but lower than the level for 1970, 1971 and 1972 seasons. The average concentration of SO_2 for the total 1974 season was about the same as in previous seasons.

In table 3 of this report the distribution of SO_2 readings recorded at Wawa on a monthly basis is shown. Approximately 90% of the readings during 1974 were below 0.25 ppm. A total of 554 hours of SO_2 were recorded and of these readings 11.4% were above 0.25 ppm, 5.8% were above 0.50 ppm and 0.7% were above 1.00 ppm. The 0.25 ppm level was exceeded during each month of the season, the 0.50 ppm level every month but August and the 1.00 ppm level was exceeded in July and October. A total of 4 hours of SO_2 in excess of 1.00 ppm was recorded, three hours in July and one hour in October. The maximum one-hour concentration was 1.32 ppm and this occurred on October 1st.

Vegetation injury by SO_2 has occurred in the Wawa area every year since monitoring of the ground level concentrations began in 1961. Over the years it has been noted that acute injury often occurs when the following concentrations are reached or exceeded for the following time periods during daylight hours.

0.95 ppm for 1 hour
or 0.55 ppm for 2 hours
or 0.35 ppm for 4 hours
or 0.25 ppm for 8 hours

For convenience sake an intensity factor of 100 has been assigned to any of the above combinations and any daytime fumigation with an intensity of 100 or more is considered to be a potentially injurious fumigation with regard to vegetation.

During 1974 (mid May to mid October) four potentially injurious fumigations occurred, one in July, two in September and one in October. The dates and intensities of the fumigations are listed below:

Date	Intensity
July 5	169
September 1	216
September 15	172
October 1	156

d) Sulphur Dioxide Levels at Goudreau During the 1974 Season:

A second continuous sulphur dioxide analyzer was operated at Goudreau, 35 kilometres northeast of Wawa by the Ontario Ministry of the Environment during the 1974 season. Ground level concentrations of SO_2 were measured at this location from May 15th. to October 16th., 1974 and valid data was obtained for approximately 62% of the sampling time. The monitor at Goudreau has been operated every season since 1961.

In table 4 of this report the data collected at Goudreau are summarized on a monthly basis for the 1974 season.

During May some level of SO_2 was recorded for 28.2% of the sampling time. The 0.25 ppm level was exceeded for three hours during the month and the maximum one-hour reading during the month was 0.31 ppm.

During June SO_2 was recorded approximately 33% of the time. The maximum one-hour concentration for the month was 0.64 ppm and there were a total of twelve hours of SO_2 above the 0.25 ppm level. Valid data was collected for 64% of the total period during June.

Approximately 35% of the readings during the month of July were SO_2 readings. There were 7 hourly readings above 0.25 ppm and 2 hours above 0.50 ppm. The maximum concentration for the month was 0.87 ppm. Valid data were collected for 65% of the total period.

Because of frequent power failures and equipment breakdowns valid data were collected for only 43% of the total period in August. Some level of SO_2 was recorded during 34% of the sampling time and the maximum one-hour concentration was 0.23 ppm.

During the first 16 days of October SO_2 was recorded about 29% of the time. The maximum one-hour concentration was 0.48 ppm and there was only one hour of SO_2 above 0.25 ppm.

In table 5 of this report, the data collected during the 1974 season are compared to that collected during the previous four seasons.

There was only one potentially injurious fumigation recorded during the season and this was on July 27th. and the intensity for the fumigation was calculated to be 109. It is possible that more than one such fumigation did occur and remained undetected since valid data were collected for only 62% of the season. The maximum intensity of any fumigation recorded during May was 60, June - 61, July - 109, August - 14, September - 25 and October - 25.

During 1970, 1971 and 1972 there were no potentially injurious fumigations recorded at Goudreau. Three such fumigations were recorded in 1973.

The number of sampling hours during 1974 was less than in most seasons and this was due to frequent equipment breakdowns, particularly during July and August.

There were a total of 931 hours of SO_2 recorded from mid May to mid October of 1974. This is the highest number of SO_2 readings recorded at this station in the past five years. About 75% of the SO_2 readings were in the range of 0.01 to 0.04 ppm.

In table 5, the maximum half-hour concentrations for the months of June, July, August, September and October for the years 1970 to 1973 are shown. In 1974, a new method was developed for reporting data and for 1974 half-hour concentrations were no longer calculated. Instead, one-hour concentrations were utilized. The maximum hourly concentration for the 1974 season was 0.87 ppm and this occurred on July 27th.

The average concentrations for SO_2 periods and total periods have varied over the past five years. This is probably due to changes in emissions, changes in frequency of wind directions and meteorological stability factors.

II. Vegetation Injury by Sulphur Dioxide in the Wawa Area During 1974:

Emissions of sulphur dioxide from the Algoma Ore Division, Algoma Steel Corporation sinter plant at Wawa over the past several years have caused acute injury to vegetation in the Wawa area. The fume damage area has been mapped each season since 1961 by various Government agencies. The degree and extent of injury has varied from season to season depending upon SO_2 emissions, frequency of wind directions and a number of biological factors.

During the 1974 season (May to October) monthly surveillance visits were made in the Wawa area to determine the incidence and extent of acute vegetation injury by SO_2.

During the May surveillance no SO_2 injury was observed on 1974 foliage in the Town of Wawa or in the area to the northeast of the Town.

About the second week in June light (6 - 15% of leaf area affected) to severe (more than 35% of leaf area affected) SO_2 injury occurred on white birch, pin cherry, red raspberry, red clover, dandelion and vetch in the Town of Wawa. The area in which the vegetation was injured was restricted to not more than 8 square kilometres.

At Lucy Pit (approximately 12 kilometres northeast of Wawa), light to severe SO_2 injury occurred early in June on white birch, trembling aspen, pin cherry, aster, blackberry and dandelion.

Sulphur dioxide injury was noted on vegetation from approximately 12 km to 16 km to the northeast of Wawa in June. In this area trace (1 - 5% of leaf area affected) to light injury was evidence on a few small white birch trees and red raspberry plants.

On July 5th., 1974, a fumigation of SO_2 with an intensity of 169 was recorded at the SO_2 monitor at 29 Hillcrest Avenue, Wawa. This fumigation caused severe injury to raspberry, black currants, beets and carrots, in a number of gardens in the Town of Wawa. Moderate (16 - 35% of leaf area affected) injury occurred on several white birch trees in the northeast portion of the Town.

Light to moderate SO_2 injury occurred on white birch trees in an 8 to 10 square kilometre area south of the sinter plant. This injury appeared to have occurred about the second week in July.

By the third week in July injury to vegetation had occurred in an area of approximately 200 square kilometres. Trace to severe SO_2 injury was observed at a maximum distance of 35 kilometres to the northeast of Wawa. White birch, trembling aspen, and pin cherry were the most frequently injured tree species in this area. Other plant species such as showy mountain ash, bracken fern and red raspberry were also injured to some extent in this area.

During August of 1974 there was no recent vegetation injury by SO_2 observed in the Town of Wawa. The only SO_2 injury noted during the August surveillance occurred to the foliage of white birch, trembling aspen, blackberry and raspberry in the area northeast of the sintering plant. The maximum distance at which this new injury was observed was about 30 kilometres to the northeast of Wawa. The most severe injury on these species was observed about 15 kilometres northeast of Wawa.

No recent, acute SO_2 injury was observed during the September or October surveillance visits in the Wawa area.

In summary, acute SO_2 injury occurred (during the 1974 season) on a number of plant species over approximately the same general area (200 square kilometres) to the northeast of Wawa as has been affected in previous seasons. Sulphur dioxide injury was more frequent and more

severe in the Town of Wawa in 1974 than in most previous seasons.

III. Wawa Area Vegetation Study Plots - Program Outline:

In 1969, the Ministry of the Environment, in co-operation with the Ministry of Natural Resources, established six surveillance plots in a transect line northeast of the sinter plant and two control plots located outside the Fume Damage Area as follows:

Plot No.	Distance and Direction From the Sinter Plant	Plot Location
1	16 km NE	Parks Lake
2	19 km NE	Finger Lake
3	26 km NE	Perry Lake
4	30 km NE	Garbe Lake
5	35 km NE	Goudreau
6	38 km NE	Herman Lake
7 (Control Plot)	61 km NE	Crouche Lake
8 (Control Plot)	56 km NW	Obatanga Park

In 1974, the surveillance plots were re-aligned to some degree. A new plot was established at Lucy Pit, 10 kilometres northeast of the sinter plant. Plot 6 (Herman Lake) was suffering adverse effects as a result of a local human activity and was therefore relocated at Troupe Lake approximately 2 kilometres west of the original position at Herman Lake. The control plot at Crouche Lake (Plot 7) was deteriorating as a result of erosion of the soil material and windthrow of the larger trees, therefore it was relocated on the Dubreuil Road approximately 45 kilometres northeast of the source. As a result of these changes, the plots have been re-numbered as follows:

Plot No.	Distance and Direction From the Sinter Plant	Plot Location
1	10 km NE	Lucy Pit
2	16 km NE	Parks Lake
3	19 km NE	Finger Lake
4	26 km NE	Perry Lake
5	30 km NE	Garbe Lake
6	35 km NE	Goudreau
7	40 km NE	Troupe Lake
8 (Control Plot)	45 km NE	Dubreuil Road
9 (Control Plot)	56 km NW	Obatanga Park

(A map of the locations is found in Figure 1)

When the plots were established in 1969, 10 trees (white birch and/or trembling aspen) and 10 shrubs (showy mountain ash, mountain maple, prairie willow, dogwood, elderberry, pin cherry, speckled alder, beaked hazel or serviceberry) were selected and tagged in a 215 metre x 215 metre area at each plot. Similar tagging operations were carried out at the plots newly established in 1974.

The "crown condition" of the trees was recorded along with insect, disease or sulphur dioxide injury, in order to establish a history of the vegetation on the plots. The crown conditions of the tagged trees are determined in June, July and August each year. As well, in September of each year, the heights and diameters of these trees are recorded for use in growth studies.

At each of the original plots, two 1 metre x 1 metre ground cover vegetation grids were established and the number and species of each type of plant found on these grids were recorded to determine if any differences in plant populations existed with distance from the sinter plant. These grids were examined in the month of August from 1969 to 1973. In 1974 the program was altered and a number of randomly located grids were examined. No permanent grids were set out at the plots established in 1974.

A program of sampling the vegetation and soil was also initiated in 1970. Leaf samples from trembling aspen, white birch, mountain maple (or substitute); forage and soil (0 - 10 cm) were collected from each of the plots in June, July, August and September and analyzed for fluoride, total sulphur, arsenic, iron and zinc. Analysis of fluoride was not continued when the 1970 results showed that this element was not a problem in the Wawa area. This sampling and analysis program was continued in June, July and August from 1971 to 1973.

In 1974, the sampling program was altered such that foliage of white birch and mountain maple (if available), forage and soil (0 - 10 cm) were collected at the plots encompassed in the newly aligned surveillance network. These samples are presently being analyzed for total sulphur, arsenic, iron and zinc.

In 1970, a lead peroxide candle, to measure ambient levels of sulphur dioxide was set out at each of the vegetation plots and these candles were exchanged at monthly intervals throughout the 1970, 1971, 1972 and 1973 growing seasons. In 1974, the candle survey was re-aligned to correspond with the vegetation surveillance plots.

Tree Crown Conditions:

In order to evaluate the crown conditions of the tagged trees and record any changes over the years, the crowns of the tagged trees have been rated three times each year during the growing season since the establishment of each plot. A system developed by the Canadian Forestry Service for the classification of hardwood tree species in Ontario was utilized. Under this system a healthy tree is assigned a value of 1A, while a dead tree is termed 6A. Classification categories between 1A and 6A can describe accurately the intermediate conditions observed among tree crowns.

The crown conditions are affected by many factors, a few being mechanical damage, insect and disease injury, and sulphur dioxide injury. The classifications assigned to the tree crowns in table 6 are based on the actual condition of the crown but are not indicative of the cause of that particular condition. Monthly surveillance studies conducted in the Wawa area from 1969 to 1974 have noted the presence of fume injury and injury by other agents and this is presented in another section of the report.

Table 6 shows the crown conditions of the 180 trees and shrubs which had been tagged as of August 1974. It should be noted that all trees and shrubs in plots #1, 7 and 8 which were established in 1974 have crowns rated at 1A. In 1969, when the remainder of these plots were established, the majority of the tagged trees and shrubs had crown conditions rated at 1A. Therefore as of August, 1974, 122 trees were rated 1A (healthy), 40 were in a state of moderate decline and 18 were dead. In general, the number of trees and shrubs in the moderate decline or dead categories decreased with distance from the sinter plant. At the two control plots, out of a total of 40 individuals only 7 showed moderate decline and one died. Thirty-two specimens (80%) were assigned a condition of 1A in these control locations.

In table 7, these data are shown in another manner. This table shows the changes, which have occurred from 1969 to 1974, in the crown conditions of the 120 tagged trees and shrubs on the original 6 plots which have been monitored since the inception of the program. A total of 42 trees and shrubs showed crown deterioration. Thirty-four individuals showed improvement, while 44 remained unchanged. In general, trees and shrubs in the plots closest to the sinter plant showed the greatest deterioration in crown conditions over the past five years. At plot 4, the increased rate of damage is partly attributable to the activities of a local colony of beavers. At plot 9 (control location) only 3 trees declined in condition, 5 improved, while 12 remained unchanged.

Plant Population Studies:

In order to evaluate the effects of the sinter plant emissions on: a) the number of plant species and b) the number of individuals in the fume damage area, two 1 metre x 1 metre ground cover vegetation grids were established adjacent to each study plot in 1969.

Each August (1969 - 1973) the number of trees, shrubs and herbaceous plants in each grid were determined and recorded. Statistical analysis of the five years data indicate the following:

(a) There was no significant difference in the number of trees, shrubs or herbaceous plants from one plot to another within the fume damage area.

(b) There was no significant difference in the average number of individuals per grid between the grids within the fume damage area and those at control locations.

(c) The number of species did not vary greatly from grid to grid within the fume damage area or in the control locations.

(d) There was little variation in the number of plant species and the number of individuals at the various grids over the five year period.

As this study progressed it became apparent that factors such as micro-climate, mechanical damage and canopy cover were influencing the plant populations to a greater extent than the sinter plant emissions. Therefore in 1974 the plant population study in the Wawa area was modified. This new study concentrated more attention on the absence or presence of plant species and considered larger areas than the former grids. During the 1975 season, the plant population studies will be further modified and when sufficient data are available a report will be prepared on the results. The original sixteen grids are still intact and could be reactivated if necessary.

Chemical Analysis of Vegetation and Soil Samples 1971 - 1973:

Samples of white birch, trembling aspen, showy mountain ash, mountain maple, forage and soil have been collected in the vicinity of the original Wawa Vegetation Study Plots during June, July and August each year since 1970. The samples have been analyzed for total sulphur, arsenic, iron and zinc. Techniques for chemical analysis, particularly As, were subsequently modified, therefore the results for only the 1971 - 1973 seasons are comparable.

In table 8 the levels of Fe, As, Zn and To S for the three seasons are shown. The plot numbers in this table refer to the original 8 plots. At the time this report was prepared the analysis of the 1974 samples had not been completed and therefore these data are not included in this table. The levels of Fe, As and Zn in table 8 are in parts per million and To S is expressed as per-cent. In most cases the levels in the vegetation are presented as an average of three samples (June, July and August) and the soil on the basis of two samples (June and August).

Leaf samples collected from white birch and trembling aspen trees at the six plots in the "Fume Damage Area" had higher levels of Fe, As and To S than samples collected at control locations. The levels of these elements were highest at plot #1, 16 km NE of the sinter plant and in general decreased with increased distance from the source. There was some variation in the levels of these elements from season to season. However this is expected as there is considerable variation in weather and growth conditions from year to year. There was considerable variation in the zinc levels from plot to plot and from season to season. It appears that zinc is not a problem in the Wawa area since in some cases the zinc levels are higher at the control plots than at the plots closest to the source.

Chemical analysis of leaf samples from the two shrubs (showy mountain ash and mountain maple) collected at the plots in the "Fume Damage Area" showed about the same trends from plot to plot and season to season for Fe, As and To S content as did the samples of trembling aspen and white birch. The levels of Zn in both the shrubs were about the same from plot to plot (25 - 50 ppm range). This is considerably lower than the levels in the aspen and white birch samples where concentrations in the range of 200 - 300 ppm were common. Trembling aspen and white birch must preferentially take up zinc and concentrate this element in the leaves.

The levels of Fe, As, Zn and To S reported for forage are for not washed samples. Elevated levels of Fe, As and To S were present only at plot #1, 16 km NE of the source. Levels at other plots were in the same range as those collected at control locations. In general, the levels of Fe, As and Zn were considerably lower in the forage than in the tree or shrub leaf samples at each plot. The sulphur levels in forage at a particular plot were about the same as the levels of sulphur in the tree or shrub leaf samples.

On page 32 the levels of Fe (%), As (ppm), Zn (ppm) and To S (%) in the soil samples collected in the Wawa area are listed. Elevated levels of Fe (greater than 1%) were found in almost all of the soil samples collected in the "Fume Damage Area". The high levels of iron in the soil in this area are partly due to natural conditions in combination with the emissions from the sinter plant. The levels of As were elevated in the soils at #1, 2 and 4. The elevated arsenic levels at these locations are mainly the result of the sinter plant emissions.

In table 9 the statistical analysis for the relationship between species, stations and elemental content for the period 1970 to 1973 is shown.

The sulphur content in vegetation samples collected in 1973 at plots #1 and 2 is significantly higher than that in those collected at plots #6, 7 and 8. The sulphur level in vegetation at plot #1 is significantly higher than that in the samples collected at plots #3, 4 and 5 and the levels at plot #2 are significantly higher than those at plots #6, 7 and 8.

The arsenic levels in vegetation samples from plots #1 and 2 were significantly higher than the levels in samples collected at plots #7 and 8.

Iron levels in samples from plot #1 were significantly higher than samples collected at all the other plots.

There was no significant difference in the levels of zinc from plot to plot. Sulphur, arsenic, iron and zinc levels in white birch, samples were significantly higher than in forage at all stations in samples collected during 1973.

The trends shown in sulphur, arsenic, iron and zinc levels from station to station and species to species in the foliar samples collected during 1973 were similar to those for the 1970, 1971 and 1972 seasons.

Lead Peroxide Candle Survey:

A lead peroxide candle was exposed adjacent to each of the nine Wawa area vegetation study plots during the 1974 season. The candles were exchanged approximately every 30 days. The exposed candles were later analyzed for sulphur trioxide. The results of the candle survey are shown in table 10. Since almost all of the acute

sulphur dioxide injury on vegetation in the Wawa area occurs during the months of June, July and August, the data for only these months are included. The sulphation rates, in mgm of SO_3/100 cm^2/day, for these three months of 1974 are compared to the average for the same period for the 1970, 1971, 1972 and 1973 seasons. The locations 45 km NE and 56 km NW are control plots, therefore the sulphation rates at these plots can be considered as background levels. In Ontario, from an air quality point of view, sulphation rates in excess of 0.70 mgm SO_3/100 cm^2/ day are considered unacceptable. In the Wawa area there is only one major source of SO_2 and peak levels of SO_2 occur frequently causing injury to vegetation during the growing season. Average monthly sulphation rates of 0.40 mgm of SO_3/100 cm^2/day have over the past several years been related to acute SO_2 injury to vegetation in the Wawa area. During 1974 the 0.40 level was exceeded a total of 10 times during the three month period from June to August at the seven plots within the fume damage area. The acceptable level was exceeded during each of these three months at the plots located 10 and 16 km NE of the sinter plant. Severe sulphur dioxide injury occurred on the indigenous vegetation in the vicinity of these plots where the sulphation rate of 0.40 mgm of SO_3/100 cm^2/day was exceeded during June, July and August. The highest sulphation rate, 2.13 mgm SO_3/100 cm^2/day was recorded in June at the plot 10 km NE of the sinter plant.

The sulphation rates during 1974 at the six plots in the fume damage area for which 4 year means were calculated were in most cases lower than that mean. Of the 18 total sulphation rates for 1974, 13 were lower than the corresponding means, one was the same and 4 were greater. The sulphation rates at all the plots in August of 1974 were considerably less than in June and July. The reason for the lower sulphation rates in August is probably due to a combination of factors such as plant shut downs, shifts in wind direction and dispersion conditions.

The relationship between the percent sulphur content in vegetation samples collected near the study plots and the rate of sulphation (mgm SO_3/100 cm^2/day) on the lead peroxide candles exposed at the 8 plots is shown in table 11 and figure 2. The sulphation rates are an arithmetic mean of the rates for June, July and August of 1973. The sulphur content of the vegetation (trees, shrubs and forage) is the mean of all samples collected during June, July and August. The correlation between these parameters is very high ($r = 0.987$) and is significant at the 1% level. Such correlations between the sulphur content in vegetation and the sulphation rates on candles have occurred in the Wawa area for the past several years. Those plots at which high sulphation rates and high sulphur contents have been recorded have shown the most frequent and most severe acute vegetation injury symptoms of sulphur dioxide over this same period.

SUMMARY:

Emissions of sulphur dioxide from the Algoma Ore Division sinter plant at Wawa were monitored by the Ontario Ministry of the Environment during the 1974 growing season. Concentrations of SO_2 recorded on continuous SO_2 monitors and sulphation candles were such as to cause acute vegetation injury over an approximate area of 200 square kilometres.

Vegetation and soil samples collected in 1973 northeast of Wawa contained elevated levels of sulphur, iron and arsenic. In general the levels decreased with increased distance from the source. Data collected during the past several seasons in the Wawa area have been of value in assessing the effects of the sinter plant emissions on the vegetation and soils in the "Wawa Fume Damage Area".

ACKNOWLEDGEMENTS:

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A P P E N D I X

Plot Locations and Site Descriptions

Plot #1 Location:

Lucy Pit, Algoma Ore Division approximately 10 km northeast of Wawa in the "Total Kill" section of the fume damage area.

Site Description:

A well drained area with shallow soil profile and many rock outcrops. The area is sparsely covered with a young stand of white birch and trembling aspen and Manitoba Maple. The ground cover vegetation is composed of a wide variety of plant species.

Plot #2 Location:

Parks Lake, 16 km northeast of Wawa in the "Total Kill" section of the fume damage area.

Site Description:

An open well drained site with a shallow soil profile with several rock outcrops. The area is sparsely covered with a young stand of white birch, manitoba maple and alder. The ground cover vegetation is made up mainly of grasses and blueberry plants.

Plot #3 Location:

Finger Lake, 19 km northeast of Wawa in the "Total Kill" section of the fume damage area.

Site Description:

An open well drained site. The soil profile is shallow and rock outcrops are common. The area is sparsely covered with a young stand of white birch and manitoba maple.

Plot #4 Location:

Perry Lake, 26 km northeast of Wawa in the "Heavy Kill" section of the fume damage area.

Site Description:

A poorly drained site with organic soil. Beavers have removed all the mature aspen trees leaving a sparse stand of alder and white birch. The location of this plot may be changed in 1975.

Plot #5 Location:

Garbe Lake, 30 km northeast of Wawa in the "Heavy Kill" section of the fume damage area.

Site Description:

A well drained site, with a shallow soil profile. The area is covered

Plot Locations and Site Descriptions

with a semi-mature stand of white birch and spruce.

Plot #6 Location:

Goudreau, approximately 35 km northeast of Wawa in "Light Damage" section of the Fume Damage Area.

Site Description:

A well drained site with a southern exposure. The soil profile is shallow and rock outcrops are common. The area is moderately covered with a young stand of white birch and trembling aspen.

Plot #7 Location:

Troupe Lake, 40 km northeast of Wawa in the "Light Damage" section of the Fume Damage Area. This plot was established in June of 1974 replacing the plot on the island on Herman Lake. Expansion of a tourist operation on the island interfered with the plot and making it necessary to find a new location.

Site Description:

A well drained rocky site with a shallow soil profile. The area forested with a semi-mature stand of trembling aspen, white birch and spruce.

Plot #8 Location:

A control location approximately 45 km northeast of Wawa. This plot was established along the Dubreuil Road in June of 1974 and replaces the former control plot at Crouche Lake. Road construction and wind damage made it necessary to relocate this plot.

Site Description:

A well drained sandy soil. The area is covered with a young stand of white birch, trembling aspen and spruce. The undercover consists of alder and a wide range of grasses, sedges, blueberry and other plant species.

Plot #9 Location:

A control location in the Obatanga Provincial Park, approximately 56 km northwest of Wawa.

Site Description:

A poorly drained location, covered with a mature stand of white birch, trembling aspen, spruce and balsam fir.

* Personnel from the Ministry of Natural Resources at Wawa have mapped the Wawa Fume Damage Area by air for the past several years and the terms "Total Kill", "Heavy Damage" and "Light Damage" are the terms used by them to describe the three injury zones.

FIGURE 1

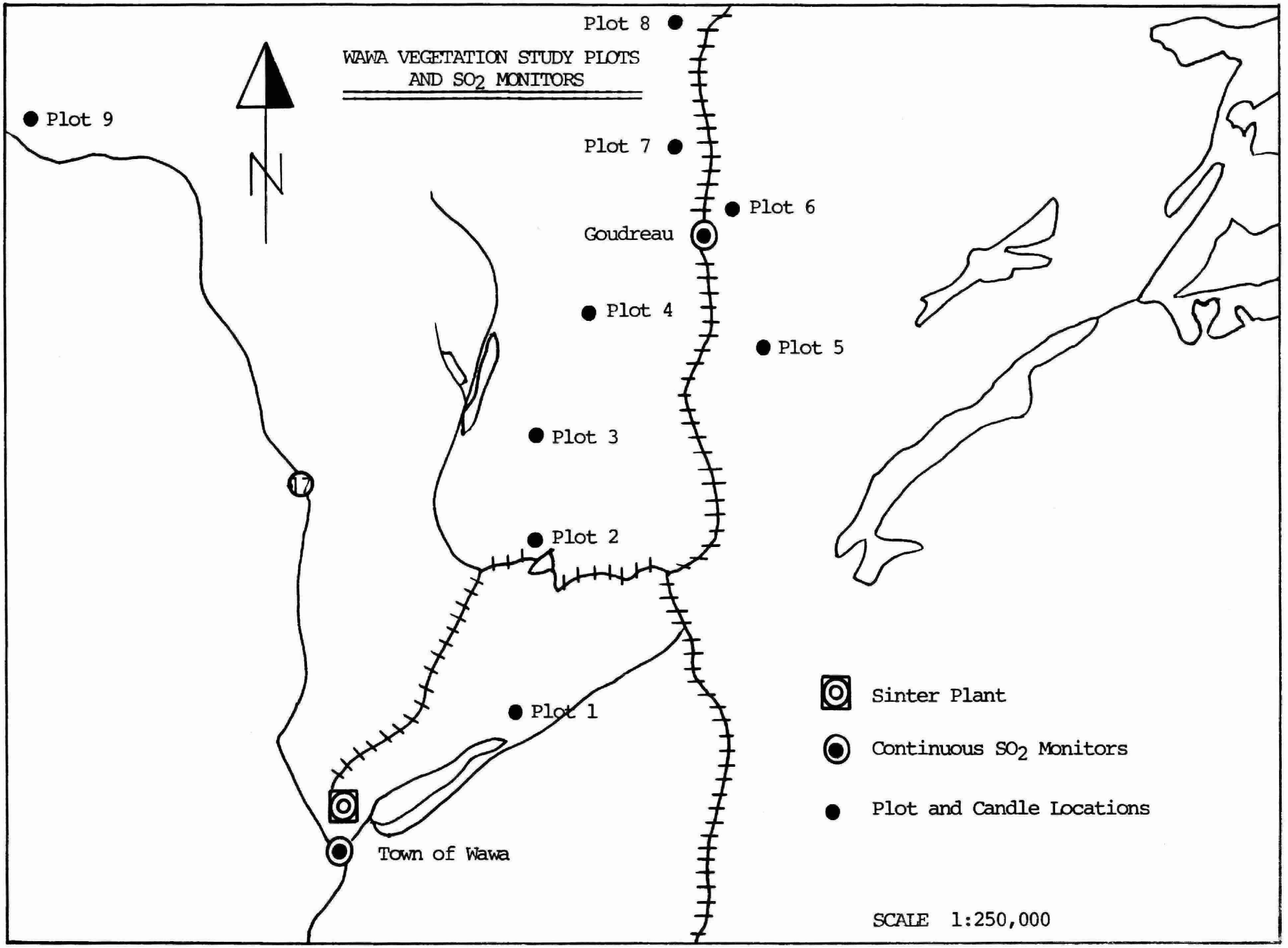

WAWA VEGETATION STUDY PLOTS
AND SO_2 MONITORS
N
Plot 8
Plot 9
Plot 7
Plot 6
Goudreau
Plot 4
Plot 5
Plot 3
Plot 2
Plot 1
Town of Wawa
Sinter Plant
Continuous SO_2 Monitors
Plot and Candle Locations
SCALE 1:250,000

Figure 2: RELATIONSHIP BETWEEN SULPHATION RATES ON LEAD PEROXIDE CANDLES AND TOTAL SULPHUR IN VEGETATION SAMPLES COLLECTED IN THE WAWA AREA DURING 1973

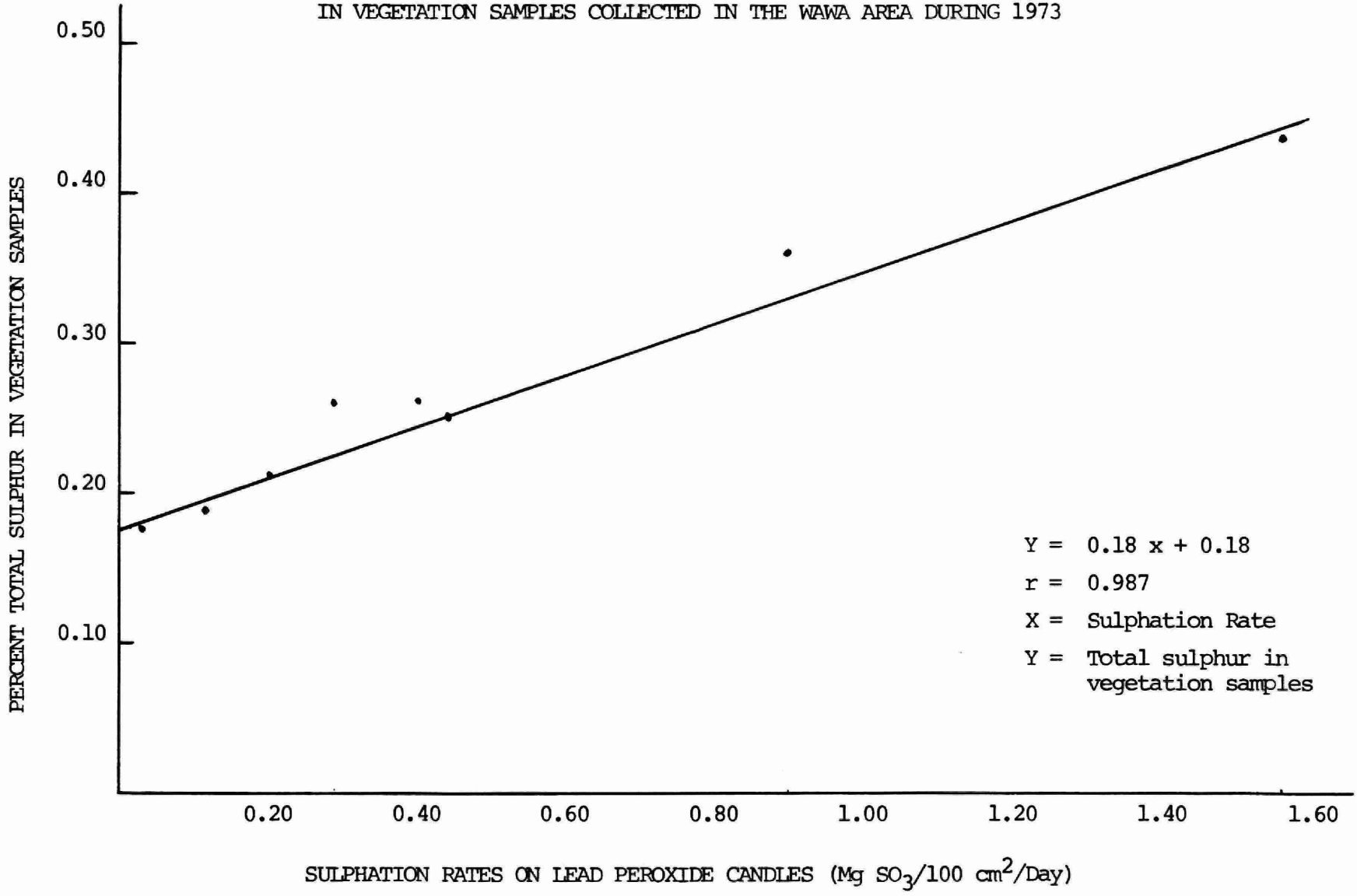


Table 1: *PRODUCTION AND EMISSION DATA FROM THE ALGOMA ORE DIVISION SINTER PLANT AT WAWA DURING 1974 (JUNE THROUGH SEPTEMBER)

Month	Raw Ore Feed Gross Tons	Sinter Produced	SO_2 Lost G.T.
June	267,559	171,142	17,180
July	272,361	168,282	14,742
August	273,228	172,566	15,732
September	245,625	152,754	15,540
TOTAL	1,058,773	664,744	63,194

* Data Supplied By Algoma Ore Division, Algoma Steel Corporation

Table 2: Summary of the Sulphur Dioxide Data Recorded In the Town of Wawa During the Growing Seasons of 1970-1974.

Year	Total Sampling Time (Hrs.)	Zero Readings Hrs.	Zero Readings %	Readings hrs.	Readings %	Maximum ½ hour Concentration (ppm)	Average ppm for SO_2 Periods Only	Average ppm for Total Period
				-------June-------				
1970	651.0	634.5	97.4	16.5	2.5	0.48	.09	.01
1971	537.0	524.0	97.5	13.0	2.4	1.73	.26	.01
1972	535.5	526.5	98.3	9.0	1.7	0.40	.05	.01
1973	704.0	280.5	39.8	423.5	60.2	0.17	.01	.01
1974	694.0	551.0	79.4	143.0	20.6	0.56 *	.02	.01
				-------July--------				
1970	744.0	740.5	99.6	3.5	0.4	0.10	.06	.01
1971	743.0	727.0	97.8	16.0	2.1	0.72	.10	.01
1972	738.0	724.5	98.2	13.5	1.8	0.26	.05	.01
1973	744.0	571.0	76.7	173.0	23.3	0.65	.02	.01
1974	713.0	570.0	79.9	143.0	20.1	1.31 *	.07	.02
				--------August---------				
1970	744.0	728.0	97.8	16.0	2.2	1.22	.25	.01
1971	725.0	712.5	98.2	12.5	1.7	0.63	.20	.01
1972	739.0	706.5	95.6	32.5	4.4	1.22	.09	.01
1973	731.0	676.0	92.5	55.0	7.5	0.63	.03	.01
1974	743.0	641.0	86.3	102.0	13.7	0.42 *	.02	.01

*Maximum 1 Hour Concentration for 1974.

Table 2 Cont'd: Summary of the Sulphur Dioxide Data Recorded in the Town of Wawa During the Growing Seasons of 1970-1974.

Year	Total Sampling Time (hrs.)	Zero Readings hrs.	Zero Readings %	Readings hrs.	Readings %	Maximum ½ hour Concentration (ppm)	Average ppm for SO_2 Periods only	Average ppm for Total Period
				---------September---------				
1970	720.0	702.5	97.5	17.5	2.4	0.38	.12	.01
1971	183.0	175.5	95.9	7.5	4.0	1.84	.51	.02
1972	418.5	403.0	96.3	15.5	3.7	0.39	.11	.01
1973	717.0	583.0	81.3	134.0	18.7	1.79	.13	.02
1974	719.0	698.0	89.8	73.0	10.2	0.98 *	.18	.02
				----------October----------				
1970	488.0	462.0	94.7	26.0	5.3	0.78	.15	.01
1971	471.5	461.5	97.8	10.0	2.0	1.06	.22	.01
1972	611.5	558.0	91.3	53.5	8.7	2.03	.39	.04
1973	372.0	261.5	70.3	110.5	29.7	1.78	.19	.05
1974	377.0	346.0	91.8	31.0	8.2	0.16 *	.35	.03
				----------Season----------				
1970	3618.5	3531.0	97.6	87.5	2.4	1.22	.16	.01
1971	2658.5	2600.5	1 97.8	59.0	0.2	1.84	.23	.01
1972	3214.0	3085.0	96.0	129.0	4.0	2.03	.21	.01
1973	3540.5	2427.0	68.5	1113.5	31.5	1.79	.05	.01
1974	3653.0	3099.0	34.2	554.0	15.2	1.32 *	.08	.01

* Maximum 1 hour concentration for 1974

Table 3: Summary of the Sulphur Dioxide Data Recorded at Wawa During the 1974 Season

Total Sampling Time (hr)	Total Hours of SO_2	%	Hours Above 0.25 ppm	%	0.50 ppm	%	1.00 ppm	%	Maximum 1 Hr. Conc. (ppm)
			----------May----------						
407	62	15.2	11	17.7	4	6.4	0	0.0	0.84
			---------June----------						
694	143	20.6	4	2.8	1	0.6	0	0.0	0.56
			---------July----------						
713	143	20.1	13	13.1	8	5.6	3	2.1	1.31
			--------August---------						
743	102	13.7	1	0.9	0	0.0	0	0.0	0.42
			------September--------						
719	73	10.2	17	23.3	11	15.1	0	0.0	0.98
			-------October---------						
377	31	8.2	17	54.8	8	25.8	1	3.2	1.32
			--------SEASON---------						
3653	554	15.2	63	11.4	32	5.8	4	0.7	1.32

Table 4: SUMMARY OF THE SULPHUR DIOXIDE RECORDED AT GOUDREAU DURING THE 1974 SEASON

Month	Total Sampling Time (Hr.)	Total Hours Of SO_2	%	Hours Above 0.25 ppm	%	0.50 ppm	%	1.00 ppm	%	Maximum 1 Hour Concentration
May	396	112	28.2	3.0	2.6	0.0	0.0	0.0	0.0	0.31
June	462	151	32.7	12.0	7.9	0.0	0.0	0.0	0.0	0.46
July	413	159	34.8	7.0	4.3	2.0	0.0	0.0	0.0	0.87
August	243	129	34.8	0.0	0.0	0.0	0.0	0.0	0.0	0.23
September	656	270	41.2	0.0	0.0	0.0	0.0	0.0	0.0	0.23
October	347	110	31.7	1.0	1.0	0.0	0.0	0.0	0.0	0.48
Season	2517	931	37.0	23.0	2.5	2.0	0.2	0.0	0.0	0.87

Table 5: SUMMARY OF SULPHUR DIOXIDE DATA RECORDED AT GOUDREAU 1970-1974

Year	Sampling Time (Hrs.)	Hrs. of SO_2	%	Maximum ½ Hour Conc. ppm	Average ppm for SO_2 Periods	Average ppm for Total Periods
		---------JUNE----------				
1970	720.0	80.0	11.1	0.30	0.06	0.01
1971	476.0	38.5	8.1	0.28	0.07	0.01
1972	446.5	82.0	18.4	0.08	0.03	0.01
1973	678.0	185	27.3	0.46	0.06	0.02
1974	462.0	151	32.7	0.46*	0.08	0.03
		---------JULY----------				
1970	711.0	27.5	3.9	0.27	0.07	0.01
1971	744.0	175.0	24.0	0.42	0.06	0.02
1972	538.5	159.5	29.6	0.21	0.06	0.02
1973	592.0	98.5	16.6	0.97	0.08	0.01
1974	413.0	163.0	33.9	0.87*	0.06	0.02

* Max. One Hour Concentration for 1974

Table 5 Cont'd: SUMMARY OF SULPHUR DIOXIDE DATA
RECORDED AT GOUDREAU 1970-1974

Year	Sampling Time (Hrs.)	Hrs. of SO_2	%	Maximum ½ Hour Conc. ppm	Average ppm for SO_2 Periods	Total Periods
		---------AUGUST---------				
1970	452.0	25.0	5.5	0.11	0.04	0.01
1971	744.0	83.5	11.5	0.48	0.08	0.01
1972	626.0	242.5	38.7	0.32	0.02	0.01
1973	702.0	135.0	19.2	0.53	0.07	0.01
1974	243.0	132.0	41.9	0.23*	0.03	0.01
		--------SEPTEMBER--------				
1970	678.5	29.5	4.4	0.31	0.05	0.01
1971	720.0	17.5	5.1	0.19	0.04	0.01
1972	671.5	125.5	18.7	0.10	0.01	0.01
1973	714.5	75.5	10.6	0.97	0.09	0.01
1974	656.0	27.0	41.2	0.23*	0.02	0.01

* Max. One Hour Concentration for 1974.

Table 5 Cont'd: SUMMARY OF SULPHUR DIOXIDE DATA
RECORDED AT GOUDREAU 1970-1974

Year	Sampling Time (Hrs.)	Hrs. of SO_2	%	Maximum ½ Hour Conc. ppm	Average ppm for SO_2 Periods	Average ppm for Total Periods
		----------OCTOBER----------				
1970	468.0	29.0	6.2	0.16	0.03	0.01
1971	225.0	5.0	2.2	0.13	0.04	0.01
1972	--	--	--	--	--	--
1973	195.0	47.5	24.4	1.38	0.17	0.02
1974	347.0	110.0	31.7	0.48 *	0.03	0.01
		**				
		----------SEASON----------				
1970	3189.5	199.0	6.2	0.31	0.05	0.01
1971	3456.0	320.0	12.8	0.48	0.07	0.01
1972	2411.0	631.5	26.2	0.32	0.03	0.01
1973	3353.5	755.0	10.6	0.97	0.08	0.01
1974	2121.0	931.0	35.2	0.87 *	0.04	0.02

* Max. One Hour Concentration for 1974.
** June - October

Table 6: CROWN CONDITIONS OF TREES AND SHRUBS
IN WAWA VEGETATION STUDY PLOTS, AUGUST, 1974.

PLOT NO.	LOCATION & DIRECTION FROM WAWA	1A HEALTHY	1B 2A 2B SOME DECLINE	3A 3B 4A 4B MODERATE DECLINE	5A 5B SEVERE DECLINE	6A DEAD
* 1	10 km NE	20	-	-	-	-
2	16 km NE	5	-	12	-	3
3	19 km NE	12	-	5	-	3
4	26 km NE	7	-	8	-	4
5	30 km NE	16	-	3	-	1
6	35 km NE	10	-	5	-	5
*7 (Control Plot)	38 km NE	20	-	-	-	-
*8 (Control Plot)	45 km NE	20	-	-	-	-
9	56 km NW	12	-	7	-	1
	TOTAL	122	0	40	0	18

* Plot Established During 1974 - Others Established in 1969.

Table 7: SUMMARY OF CHANGES IN CROWN CONDITIONS OF TREES AND SHRUBS IN WAWA VEGETATION PLOTS 1969-1974

Plot Number	Location & Direction from Wawa	Number of Trees and Shrubs Where Crown Condition Has Remained Constant	Improved	Declined
2	16 km NE	2	5	13
3	19 km NE	5	9	6
4	26 km NE	6	4	* 10
5	30 km NE	14	4	2
6	35 km NE	5	7	8
9	56 km NW	12	5	3
	TOTAL	44	34	42

* (Damage Attributed Partially to Beaver Activities)

Table 8: CONCENTRATIONS OF Fe, As, Zn AND To S IN VEGETATION AND SOIL SAMPLES COLLECTED IN THE WAWA AREA 1971-1973

Species: White Birch

Plot No.	Location	Fe (ppm)			As (ppm)			Zn (ppm)			To S%		
		1971	1972	1973	1971	1972	1973	1971	1972	1973	1971	1972	1973
1	16 km NE	325	184	407	9.0	5.4	9.3	330	322	184	.49	.41	.44
2	19 km NE	155	129	178	6.2	5.7	8.6	253	225	166	.34	.43	.32
3	26 km NE	115	92	174	3.1	3.5	4.2	270	256	80	.28	.33	.27
4	30 km NE	120	96	150	3.8	2.8	8.4	197	154	111	.32	.33	.31
5	35 km NE	96	78	111	3.0	1.3	4.0	290	255	129	.31	.26	.27
6	38 km NE	104	94	88	2.9	2.2	2.7	173	140	130	.26	.28	.22
7	61 km NE	81	68	60	1.2	1.2	0.7	188	112	131	.17	.23	.18
8	56 km NW	77	73	78	1.0	0.6	0.4	217	129	108	.19	.24	.16

Table 8 Cont'd: CONCENTRATIONS OF Fe, As, Zn AND To S IN VEGETATION AND SOIL SAMPLES COLLECTED IN THE WAWA AREA 1971-1973

Species: Trembling Aspen

Plot No.	Location	Fe (ppm)			As (ppm)			Zn (ppm)			To S%		
		1971	1972	1973	1971	1972	1973	1971	1972	1973	1971	1972	1973
1	16 km NE	124	256	231	9.1	8.1	6.8	377	391	158	.57	.61	.44
2	19 km NE	--	--	--	---	---	---	---	---	---	--	--	--
3	26 km NE	71	62	121	2.2	2.5	2.7	250	267	152	.34	.47	.34
4	30 km NE	--	--	--	---	---	---	---	---	---	--	--	--
5	35 km NE	71	55	78	2.5	2.0	2.1	225	203	183	.35	.45	.31
6	38 km NE	90	68	75	2.3	1.8	2.1	235	178	170	.34	.37	.27
7	61 km NE	72	63	74	1.5	1.1	0.5	168	179	208	.23	.31	.23
8	56 km NW	87	65	69	0.9	0.8	< 0.3	178	150	139	.36	.30	.25

Table 8 Cont'd: CONCENTRATIONS OF Fe, As, Zn AND To S IN VEGETATION AND SOIL SAMPLES COLLECTED IN THE WAWA AREA 1971-1973

Species: Mountain Maple

Plot No.	Location	Fe (ppm)			As (ppm)			Zn (ppm)			To S%		
		1971	1972	1973	1971	1972	1973	1971	1972	1973	1971	1972	1973
1	16 km NE	229	245	442	5.9	5.3	6.9	44	74	40	.35	.60	.48
2	19 km NE	128	147	273	4.6	4.2	5.8	41	53	41	.38	.52	.41
3	26 km NE	133	108	130	3.3	3.0	2.5	35	32	31	.28	.37	.30
4	30 km NE	---	---	---	---	---	---	--	--	--	--	--	--
5	35 km NE	117	128	144	2.0	2.0	1.7	33	37	45	.29	.45	.29
6	38 km NE	86	91	127	1.6	1.9	2.0	36	54	31	.22	.27	.29
7	61 km NE	81	76	78	1.1	1.0	0.3	33	52	38	.26	.27	.21
8	56 km NW	93	71	78	0.7	0.9	0.3	34	41	34	.22	.19	.23

Table 8 Cont'd: CONCENTRATIONS OF Fe, As, Zn AND To S IN VEGETATION AND SOIL SAMPLES COLLECTED IN THE WAWA AREA 1971-1973

Species: Showy Mountain Ash

Plot No.	Location	Fe (ppm)			As (ppm)			Zn (ppm)			To S%		
		1971	1972	1973	1971	1972	1973	1971	1972	1973	1971	1972	1973
1	16 km NE	250	164	298	6.7	5.3	12.6	30	25	12	.27	.51	.47
2	19 km NE	137	113	208	4.6	2.7	4.4	21	23	17	.37	.52	.36
3	26 km NE	117	82	160	2.9	2.3	3.5	18	19	18	.27	.40	.23
4	30 km NE	96	91	115	2.5	1.6	3.3	23	16	15	.29	.30	.24
5	35 km NE	---	---	---	---	---	---	--	--	--	--	--	--
6	38 km NE	124	79	108	2.5	1.7	2.1	17	22	19	.22	.21	.14
7	61 km NE	88	86	82	1.4	1.0	0.5	25	39	67	.20	.16	.16
8	56 km NW	90	67	66	0.7	0.9	< 0.3	24	60	32	.17	.16	.15

Table 8 Cont'd: CONCENTRATIONS OF Fe, As, Zn AND To S IN VEGETATION AND SOIL SAMPLES COLLECTED IN THE WAWA AREA 1971-1973

Species: Forage

Plot No.	Location	Fe (ppm)			As (ppm)			Zn (ppm)			To S%		
		1971	1972	1973	1971	1972	1973	1971	1972	1973	1971	1972	1973
1	16 km NE	120	101	156	4.4	5.4	4.3	34	59	27	.39	.44	.31
2	19 km NE	122	63	78	3.3	4.2	2.9	36	73	27	.43	.28	.34
3	26 km NE	50	67	81	2.4	4.0	3.2	33	31	22	.16	.24	.16
4	30 km NE	69	54	63	3.9	2.0	2.7	26	43	22	.27	.25	.20
5	35 km NE	87	58	53	1.7	1.9	0.8	31	23	29	.24	.24	.17
6	38 km NE	71	49	63	2.3	1.5	1.4	47	77	22	.21	.20	.15
7	61 km NE	74	49	57	1.1	1.2	< 0.3	30	53	19	.17	.22	.15
8	56 km NW	63	49	54	1.0	1.1	< 0.3	41	51	20	.30	.20	.14

Table 8 Cont'd: CONCENTRATIONS OF Fe, As, Zn AND To S IN VEGETATION AND SOIL SAMPLES COLLECTED IN THE WAWA AREA 1971-1973

Soil (0-10 cm)

Plot No.	Location	Fe (%)			As (ppm)			Zn (ppm)			To S%		
		1971	1972	1973	1971	1972	1973	1971	1972	1973	1971	1972	1973
1	16 km NE	2.83	1.24	1.06	56.5	48.4	53.0	68	48	29	.03	.03	.04
2	19 km NE	3.52	2.06	0.94	24.9	20.5	13.0	63	82	32	.06	.03	.06
3	26 km NE	0.37	0.65	2.20	6.5	6.9	2.1	17	43	5	.02	.03	.04
4	30 km NE	1.83	1.65	1.92	72.6	16.2	21.0	37	64	10	.02	.02	.04
5	35 km NE	2.39	1.35	1.20	8.4	8.2	20.0	89	89	63	.02	.03	.07
6	38 km NE	1.27	1.49	0.59	6.9	11.0	4.0	24	70	19	.02	.03	.02
7	61 km NE	0.75	0.67	0.56	4.9	3.2	1.9	27	79	15	.02	.02	.03
8	56 km NW	0.10	0.32	--	2.0	4.1	0.4	9	54	--	.01	.02	.02

Table 9: STATISTICAL ANALYSIS OF DATA COLLECTED IN THE WAWA AREA 1970-73

	Year	Sulphur	Arsenic	Iron	Zinc
PLANT SPECIES	1970	$P<0.001^{a}$	$P<0.001^{a}$	$P<0.001^{a}$	$P<0.001^{a}$
	1971	$P<0.01^{b}$	$P<0.01^{b}$	$P<0.001^{a}$	$P<0.001^{a}$
	1972	$P<0.01^{b}$	$P>0.1^{d}$	$P<0.05^{c}$	$P<0.001^{a}$
	1973	$P<0.001^{a}$	$P<0.001^{a}$	$P<0.001^{a}$	$P<0.001^{a}$
STATION	1970	$P<0.001^{a}$	$P<0.001^{a}$	$P<0.001^{a}$	$P<0.01^{b}$
	1971	$P<0.001^{a}$	$P<0.001^{a}$	$P<0.001^{a}$	$P<0.01^{b}$
	1972	$P<0.001^{a}$	$P<0.001^{a}$	$P<0.001^{a}$	$P<0.01^{b}$
	1973	$P<0.001^{a}$	$P<0.001^{a}$	$P<0.001^{a}$	$P>0.1^{d}$

a - When P<0.001 means significant at 0.1% level.

b - P<0.01 means significant at 1% level.

c - P<0.05 means significant at 5% level.

d - Means not significant.

Table 10: SULPHATION RATES IN MGM SO_3/100 CM^2/DAY ON LEAD PEROXIDE CANDLES DURING JUNE, JULY AND AUGUST OF 1974, COMPARED TO FOUR YEARS FOR EACH MONTH AT EACH PLOT.

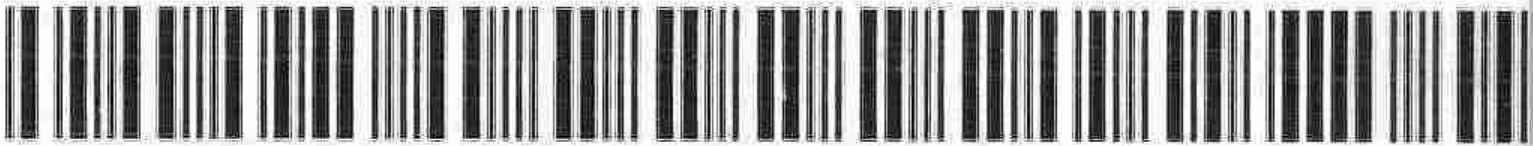
Plot No.	Location	JUNE		JULY		AUGUST		MEAN	
		Mean 1970-73	1974	Mean 1970-73	1974	Mean 1970-73	1974	Mean 1970-73	1974
1	12 km NE	---	2.13	---	1.98	---	1.30	---	1.80
2	16 km NE	1.58	1.01	1.86	1.31	0.97	0.51	1.44	0.94
3	19 km NE	0.93	0.93	1.16	0.63	0.50	0.15	0.83	0.57
4	26 km NE	0.50	0.19	0.49	0.24	0.22	0.08	0.41	0.17
5	30 km NE	0.40	0.31	0.65	0.28	0.24	0.15	0.41	0.25
6	35 km NE	0.34	0.47	0.36	0.40	0.21	0.13	0.28	0.33
7	38 km NE	0.22	0.45	0.26	0.29	0.12	0.09	0.20	0.28
8	61 km NE	0.13	0.03	0.17	0.06	0.07	0.03	0.11	0.04
9	56 km NW	0.05	0.06	0.02	0.07	0.03	0.05	0.03	0.06

Table 11: RELATION BETWEEN SULPHUR LEVELS IN VEGETATION AND SULPHATION RATES RECORDED ON LEAD PEROXIDE CANDLES IN THE WAWA AREA DURING 1973

Distance From Source	* Sulphation Rate (Ave. June, July & August)	** % Sulphur in Vegetation
16 km NE	1.56	0.45
19 km NE	0.90	0.36
26 km NE	0.40	0.26
30 km NE	0.44	0.25
35 km NE	0.29	0.26
38 km NE	0.20	0.21
61 km NE	0.11	0.19
56 km NE	0.03	0.18

* Sulphation Rate in mgm SO_3/100 cm^2/day

** Average sulphur content for all plant species collected during three samples.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